Developing Eco-friendly Concrete with Sustainable Supply: The Potential of Using Whole Recycled Gypsum Drywall

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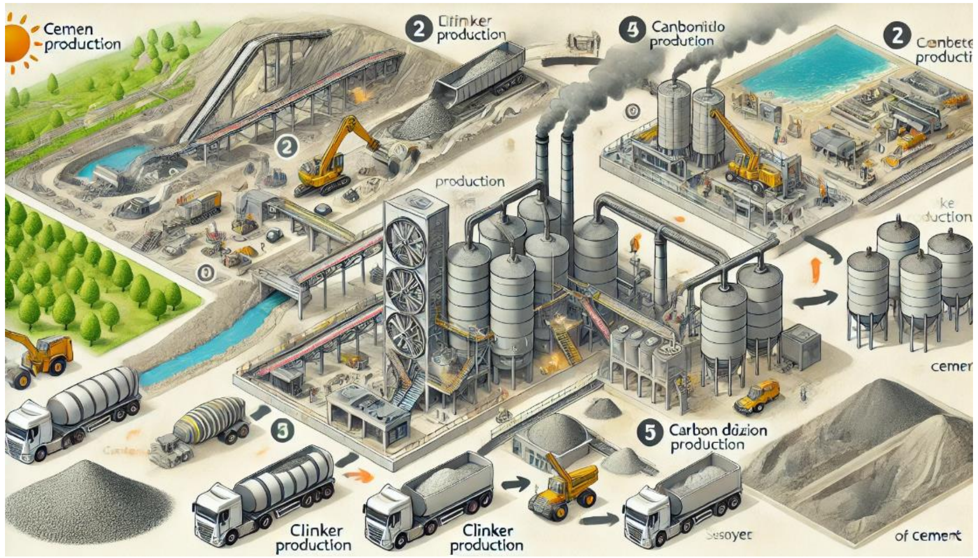
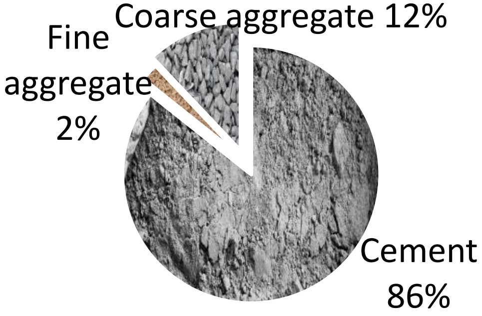
Introduction: Why replace cement?

- Cement vs environment
  - Resource depletion;
  - Strain on the planet;
  - Emitting carbon dioxide in production, storage, transportation, and reaction phases;
  - Contributing to 8% of annual carbon dioxide emissions [1];
  - Increasing the rate of global climate change.
- Still the primary binder of concrete with over 4 Billion tons supply per year (emitting 3.28 billion tons of carbon dioxide emissions) [2].
- Solution: Replacing ordinary Portland cement with eco-friendly alternatives (Supplementary cementitious materials)





Concrete CO2 emissions

Introduction: Why new supplementary cementitious materials (SCMs)?

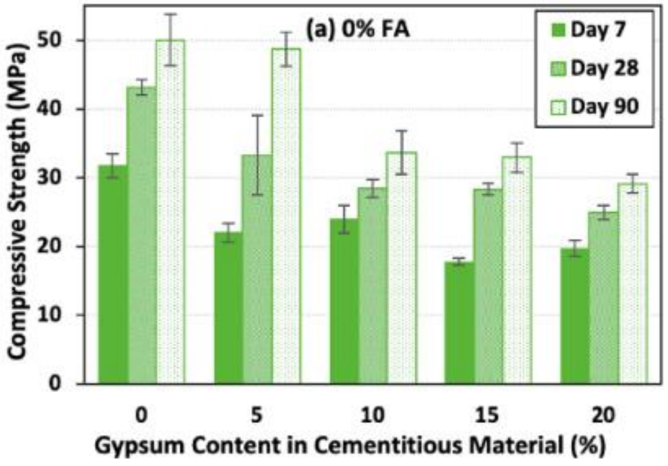
- Limited supply of SCMs compared to what required to replace ordinary Portland cement;
- New environmental regulations that restrict the source of current SCMs;
- Reducing the portion of ordinary Portland cement in cementitious composites and thereby their carbon dioxide emissions;
- Offer a sustainable waste management practice for potential materials;
- Using their features to improve strengthening reactions.

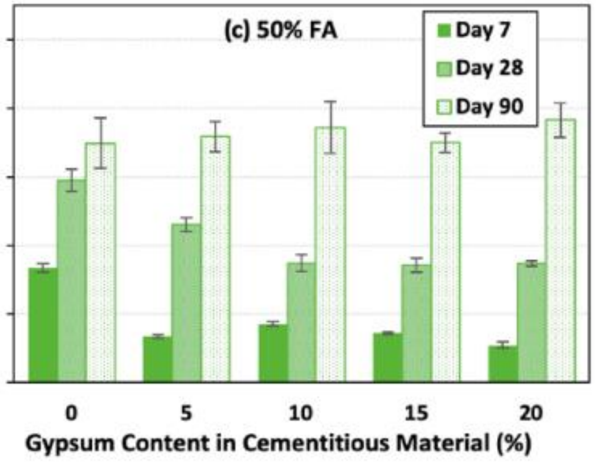
Introduction: Why recycled gypsum drywall?

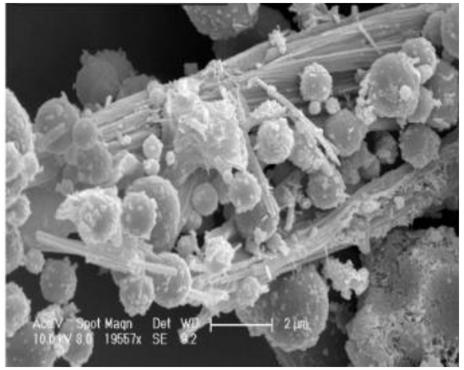
- Abundancy (20% of CDW) [3];
- Environmental benefits of recycling:
  - Prevent landfilling:
    - No toxic gas [4];
    - No water and soil contamination [4].
  - Offer waste management practice.
- Circular economy;
- Close-recycling loop [5];
- Reactivity and strength improvement [6];

Introduction: Why recycled gypsum drywall?

- Activating fly ash and slag [7-9];
- Reducing the cumulative hydration heat (by up to 73%) [10];
- Producing dense Ettringite crystals (Changing from thin needle to thick needle, frame structure) [11];
- Improving some of the durability characteristics (alkali-silica reactions) [12];
- Increase porosity [13]





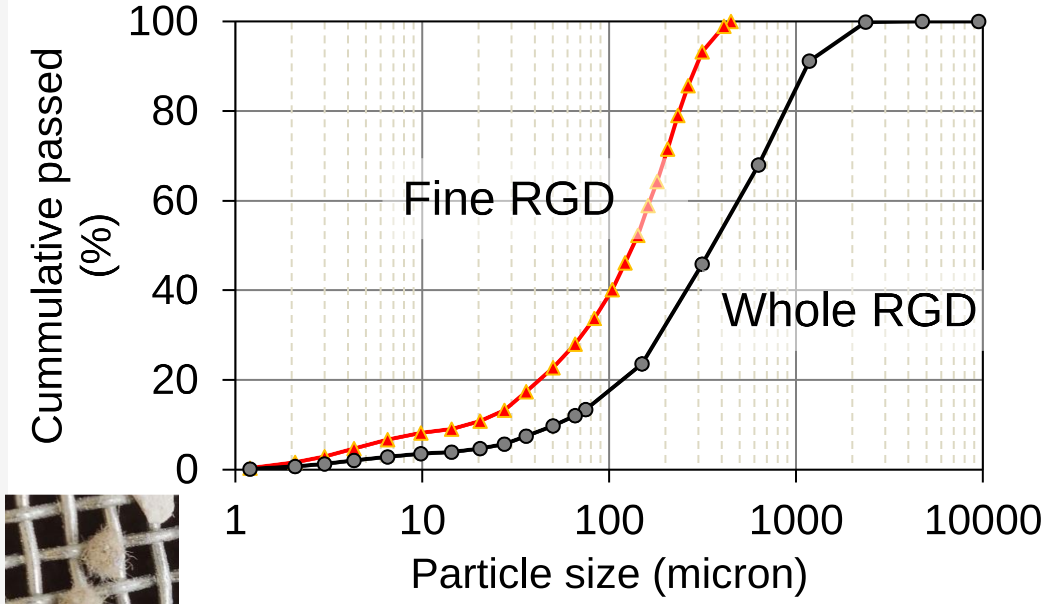


Introduction: Why reuse whole recycled gypsum drywall?

- Only 30-45 wt% of RGD passed sieve #50 (300 micron) [14];
- Returning 70-55 wt% of RGD to landfills;
- Potential of using whole RGD in concrete
  - Coarse RGD can be used as an SCM or fine aggregates.

Primary focus:

- Assessing the potential of whole RGD as a binder (cement or fly ash alternative) in high-volume fly ash concrete (comparison with fine RGD).
- Examining the short-term and long-term performance of concrete containing whole RGD, given the potential internal sulfate attack (In progress).



Coarse RGD

Fine RGD

Objectives

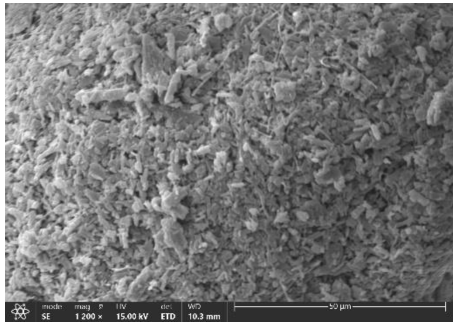
- Evaluating the feasibility of using whole RGD instead of fine RGD as an SCM in concrete:
    - Mechanical strength;
    - Ultrasonic pulse velocity;
    - Microstructure;
    - Bulk density.

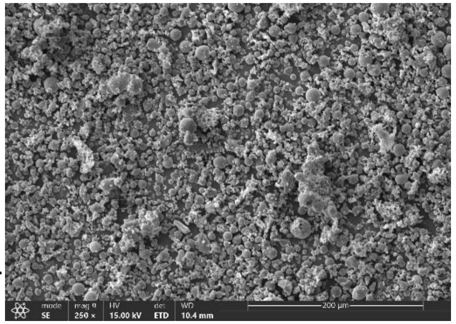
Test matrix

Binder composition

Mix design	Binder composition (%)			
	Ordinary Portland cement	Fly ash	Fine RGD	Whole RGD
F40	60	40	0	0
F50	50	50	0	0
F40WG10	50	40	0	10
F50WG10	40	50	0	10
F40FG10	50	40	10	0
F50FG10	40	50	10	0
Total of 36 concrete cylinders				

F: Fly ash
FG: Fine RGD (particles less than 300 microns)
WG: whole RGD


RGD


Fly ash

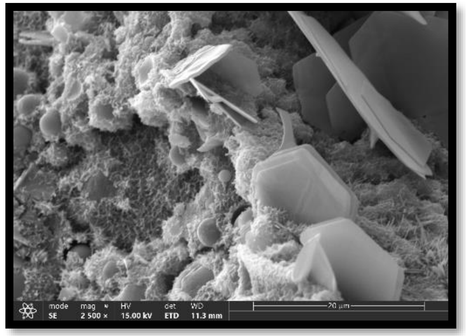
Binder properties

Characteristics (%)		Binder	
		Fly ash	RGD
Chemical compositions (%)	Ca	1.92	22.25
	Si	22.57	2.38
	Al	10.95	0.38
	Fe	9.06	0.25
	K	1.47	0.13
	Mg	0.92	0.38
	Na	0.86	0.04
	S	0.12	17.71
Physical properties	Uniformity	1.342	0.887
	Specific surface area (m^2/kg)	1409	1137

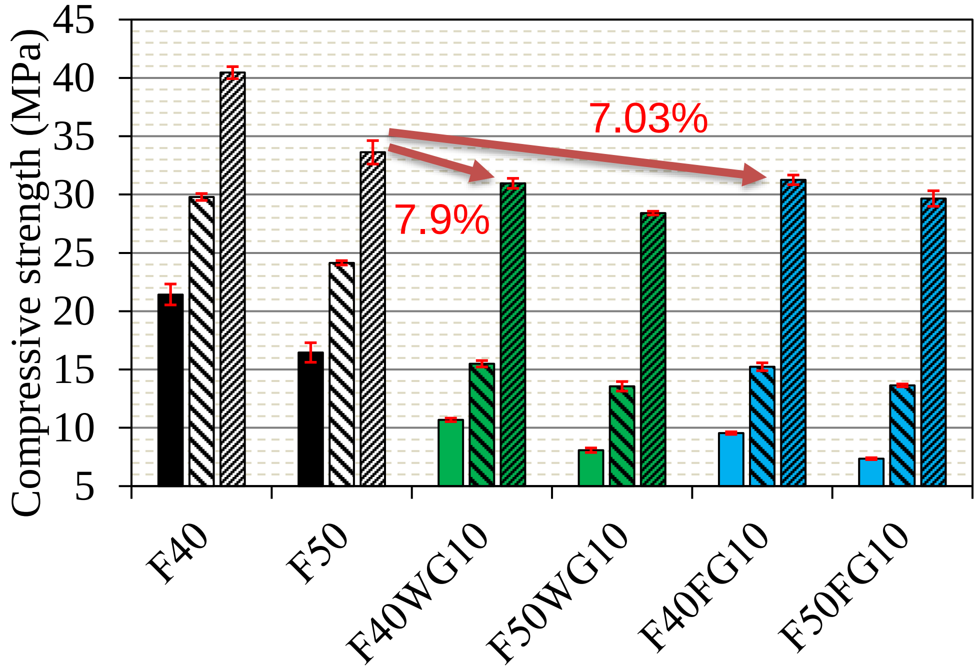
Tests

- Bulk density;
- Ultrasonic pulse velocity;
- Compressive strength;
- Microstructure.

Testing at 7, 28, and 90 days with moist curing.

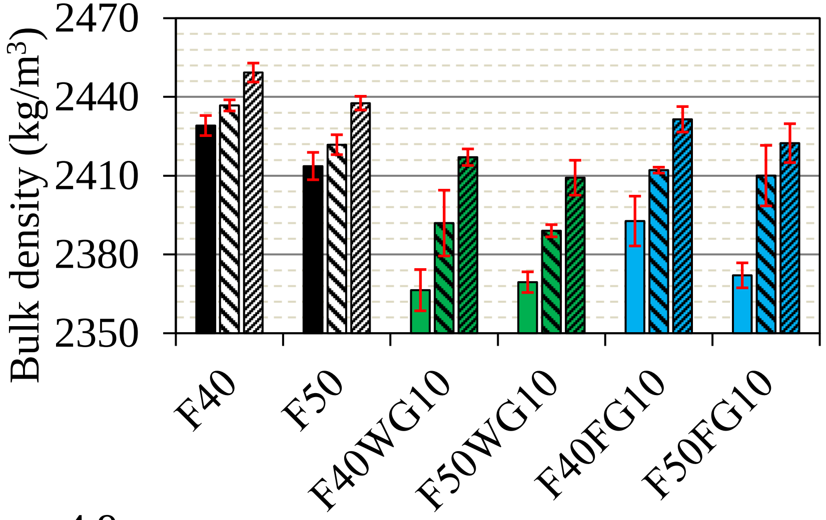


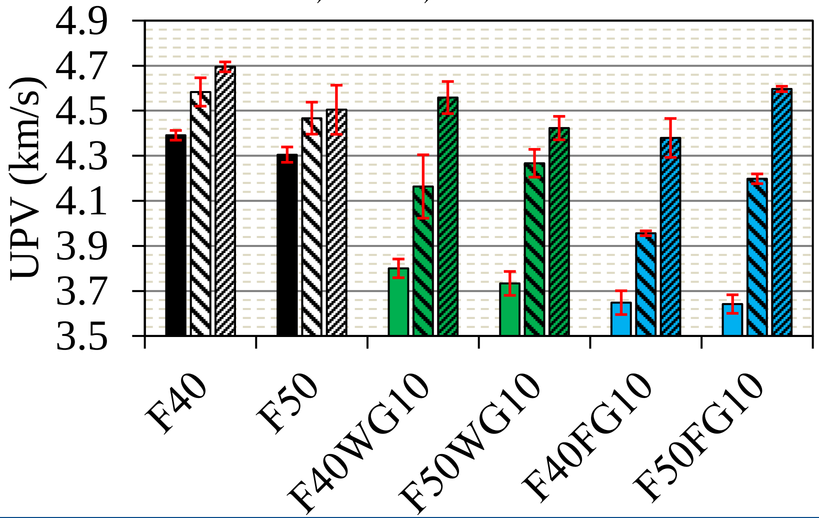
Results: Feasibility of whole RGD (Compressive strength)



- Adding RGD as a cement replacement could reduce the early age strength of concrete.
- Fine RGD and whole RGD had approximately the same influence on the compressive strength of high-volume fly ash concrete.
- RGD could be an efficient alternative for fly ash. However, the Al-to-S ratio should be used to optimize the fly ash to RGD ratio.
- Using biochar as an additive can promote the early-age strength and increase the ductility of the concrete, while reducing its carbon footprint.
- Preheating RGD could boost the early-age reactions of concrete.

Results: Feasibility of whole RGD (Porosity)

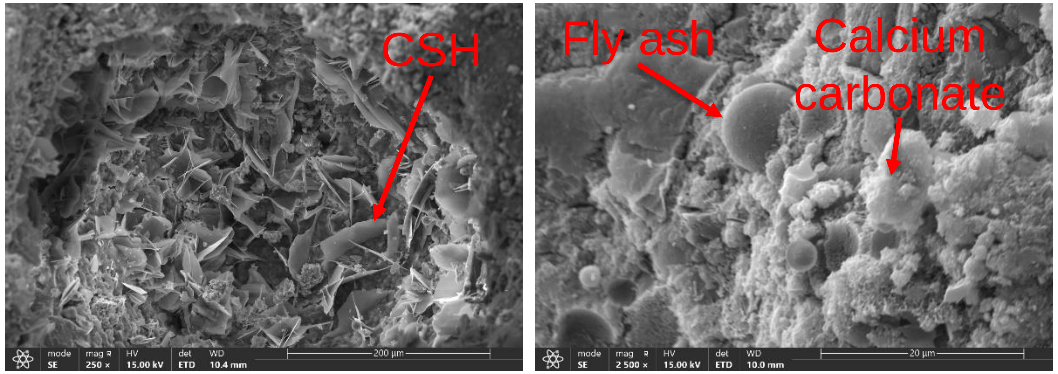




- Incorporating whole RGD as either cement or fly ash alternative reduced the bulk density of the composite at all ages, possibly due to the fiber accumulation.

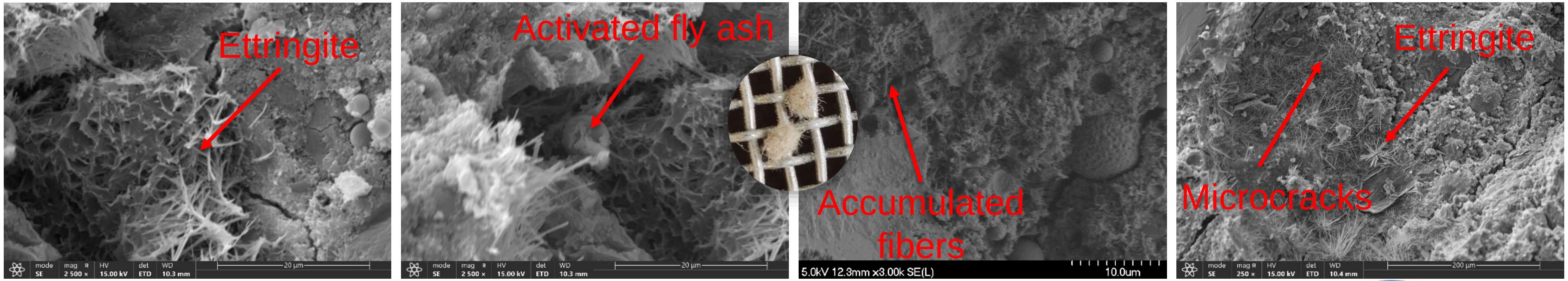
- Replacing RGD could boost the UPV of the specimens, potentially due to its effect on activating fly ash particles and forming dense ettringites.

Results: Short-term properties (microstructure)



SEM of specimens containing fly ash

- The cement paste in the mix containing fly ash is primarily composed of CSH hexagonals and calcium carbonates.
- RGD incorporation boosts the formation of concentrated ettringites.
- RGD could activate fly ash, boosting its reactivity with cement paste by offering sulfate ions.
- Incorporating RGD into concrete might cause microcracks.
- The fibers in the RGD accumulated at specific points in the system, forming weak spots in concrete.



SEM of specimens containing fly ash and whole RGD

Conclusions

- Whole RGD can be used in high-volume fly ash concrete as a replacement for both cement and fly ash.
- Replacing fly ash with RGD found to be an efficient method to reduce the portion of fly ash without sacrificing strength.
- The effect of whole RGD on the mechanical properties of the composite is similar to that of fine RGD, highlighting its potential as an SCM and preventing 70% of RGD from being landfilled.
- Using 10% RGD in concrete significantly decreases its compressive strength during the first 28 days. However, delayed reactions of RGD may enhance strength development between 28 and 90 days.
- A treatment is required to remove fibers from RGD, as fiber accumulation can create weak spots in concrete, increasing porosity and reducing strength.
- RGD promotes the formation of ettringite in the cement paste, raising concerns about the potential for internal sulfate attack.
- Adding RGD to concrete may activate fly ash particles by supplying SO_4^{2-} ions, which can dissolve alumina from fly ash and facilitate its reaction with the cement paste.

In progress research: Test matrix and tests

Short-term

- **Primary goal: Examining the effect of whole RGD as a fly ash alternative and its optimal dosage.**
- **Tests:**
  - Bulk density;
  - Ultrasonic pulse velocity;
  - Compressive strength;
  - Modulus of elasticity;
  - Microstructure.

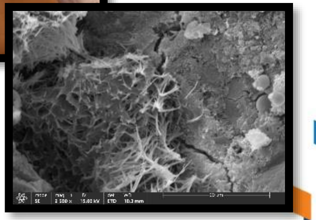
Testing at 7, 28, and 90 days with moist curing.

Mix design	Binder composition (%)		
	Blended cement	Fly ash	Whole RGD
BC100	100	0	0
BC85F15	85	15	0
BC80F20	80	20	0
BC70F30	70	30	0
BC70F25WG5	70	25	5
BC70F20WG10	70	20	10
BC70F15WG15	70	15	15
BC75F15WG10	75	15	10
Total of 216 concrete cylinders			

Long-term (Durability)

In progress research: long-term properties

- Primary goal: Examining the effect of RGD incorporation on Internal sulfate attack.
- **Test environments**
  - Dry condition;
  - Seawater (Continuous);
  - 5% sodium sulfate solution (Continuous);
  - 5% Sodium sulfate solution (Biweekly: wet and dry).
- **Test factors:**
  - Dimensions (Expansion in diameter, weekly);
  - Strength loss (1000, 3000, and 6000 hrs);
  - Modulus of elasticity (1000, 3000, and 6000 hrs);
  - Weight loss (1000, 3000, and 6000 hrs);
  - UPV (1000, 3000, and 6000 hrs);
  - Microstructure (1000, 3000, and 6000 hrs).



Thanks for your attention!

Q &A

Scan me!

My research area

Materials:
Biochar, Hydrochar, Recycled gypsum drywall, Flax, recycled aggregates, and Geopolymer and alkali-activated concrete

Duration:
Short-term (7, 28, and 90 days) and long-term (1000, 3000, and 6000 hrs)

Tests:
Compressive strength, Porosity, Microstructure, Carbon footprint, Stress-strain behavior, Wave propagation